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Technical Report No. 3

ANTENNA WITH TUNNELDIODE

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Technical Report No. 3

Antenna with Tunnel Diode

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31. March 1963

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Abstract:

This report deals with the effects of a combination consisting of an antenna and tunnel diodes. This is a first report explaining some fundamental rules in respect to the application of tunnel diodes with antennas; also the corresponding impedance measurement techniques are described. Part I of this treatment is primarily concerned with the stability problems involved in avoiding self-excitation phenomena within the system. Part II discusses the basic questions concerning the measurement of input impedance.

A folded unipole with a tunnel diode at the top of the radiator is studied experimentally as an example. The measurement of impedances with negative resistances by using slotted line techniques is also described. The next report will treat such combinations which are of technical interest.

I. Stability of Antenna Systems containing Tunnel Diodes

A. Negative Resistance Applications

The generation of a negative resistance, which is achieved either through an active four-terminal network with regenerative feedback or by using the mixing principles of a non-linear reactance, requires a relatively large number of circuit components. However the tunnel diode offers a negative resistance in the form of a single component and its application requirements as a circuit element are the same as those of a positive resistance with the exception of the following three points:

a) The tunnel diode requires a bias voltage (approx. 120 mV).

b) Its regulation range is limited to a maximum of 10-20 mV caused by the descending portion of its characteristic curve.

c) The insertion of a negative resistance introduces the possibility of self-excitation of the network; in many cases this is undesirable.

Taking the requirements listed above into consideration, the TD can be used as a negative resistance element up to an upper frequency limit "f_c" which is also the case for positive resistances and has the same cause, namely: the reactive behaviour of the conductor material. (The theoretical semiconductor effect of the TD is independent of frequency up to 10^{13} cps).

The simple use of this circuit element thus provide additional degree of freedom as far as the design of the electrical network is concerned, since the positive resistances and conductances, or the real part of impedances and admittances can be compensated for by the size of "R_n". In this respect, two application goals can be set for the use of negative resistance (excluding for the moment the use as

a self-oscillating device) and are listed below:

a) Deattenuation of a load, thus achieving an amplification effect.

b) Application of negative resistances for obtaining special impedance and admittance functions, expecially those functions having characteristic curves turning in a counter clockwise direction (influencing characteristic curves turning in a clockwise direction in respect to a wide band compensation). Amplification effect through the negative resistance in this case, is considered of no value.

   A self excitation of this current loop would disturb the operating conditions and must thus be completely avoided.

B. Network Stability

Before Networks are calculated it is normally assumed that their electrical behaviour is such that may transient excitations are of a decaying nature and after a short period of time a steady state is achieved in which the voltages and currents are then only influenced by the induced signal of the connected generators. This assumption is valid for each case of passive networks and thus need not be investigated for each individual case.

However this assumption does not necessary apply when the network contains active fourpoles with regenerative feedback and / or negative resistances. Therefore it cannot be assured that the methodes of network analysis, the complex calculation and the characteristic curve rules all fullfill the requirements for such a system. In most cases the transient oscillations of circuits incorporating negative resistances do not decay with time, rather they increase, and as a result of the non-linear limitation effects either a standing oscillation will appear or a pure exponential current increase prevents an adjustment of the operating point of the negative resistance element.

Therefore it becomes extremely desirable to associate a stability check in conjunction with the calculation of such circuits or to check the stability of an existing circuit by means of measurement. In addition it would be quite advantageous if a circuit which has been proven to be instable could be stabilised by using a suitable arrangement which does not disturb the initially preset and required circuit functions.

Both of the above mentioned problems will be treated seperately in the following text: First of all the problem of a general stability criterium check will be treated in section C - F. The stability-criterium, which is actually suitable for practical checks, is expressed at the end fo section F. Circuit recommendations which have some chance of being stable are given in section H. However in case the practical applications of them should prove to be instable outside of the operating frequency range due to stray circuit elements which are too difficult for the theoretical consideration, these circuits can be restrained from self-oscillation by means of inserting a Two-Pole-Stabilizer (Section H).

C. Practical Requirements for a Stability Check

Basically it is always possible to investigate the dynamic behaviour of a circuit via a system of differential equations when the network structure and size of the individual circuit components is completely known. The transients (general solution of the homogeneous diff. eq.) as well as these currents and voltages which are caused by the connected generator (special solution of the inhomogeneous diff. eq.) by means of the complex calculation can be calculated from these diff. eqn.

The transients of interest can hardly be calculated in practice for the following two strong reasons:

1. If the network contains more than two reactive components then the solution for the characteristic equation of the nth order is difficult and hardly possible in practice

2. The exact network structure nor the size of the individual components are actually unknown even for what appears to be a simple example. Experience has shown that even stray- and couple-reactances in the order of magnitude less than 1 nH and 1 pF respecively may not be neglected if the stability criterium of wide-band negative resistance circuits is to be investigated.

In respect to the first above mentioned difficulty, a way out can be found even for n^{th}-term networks in that one abandons the search for an explicit solution of the n-solutions of the characteristic equations, and rather determines if by means of a simple relationship of the function theory, whether the characteristic equation contains at least one solution (Eigen frequency) with a positive real part (an unlimited increasing transient oscillation).

This method (encircling criterium of F.Strecker [1] [2]) will be described only in short in the following since it has practically no meaning in respect to the second diffulty mentioned previously. However this method is of some value for the derivation of the suggested method of determining stability as will be shown in the following.

If the two previously mentioned difficulties are compared with one another then one comes to the conclusion that a practical and meaningful stability check definitely requires measurement of the network behaviour and network funcions. The measurements must be conducted so completely and with such a high degree of accuracy, that the above mentioned parasitic elements (1 nH, 1 pF) can be readily pinpointed in the measurement data.

These requirements are fulfilled by the impedance and admittance-functions; in reciprocal circuits these functions are superior to transformation functions due to the former's clarity in respect to their universally accepted definition as well as their reliable practical measurement. Since the

ideas developed here have been developed for the use of negative resistances in linear networks, reciprocity exists without a doubt. If on the other hand one is concerned with a network in which active, non-reciprocal fourpoles are considered, then the transformation functions are incorporated as checking functions (for example the Nyauist Criterium).

The preferred functions mentioned above can be found as measured characteristic impedance- or admittance curves. In addition such curves of a practical and realizable network have a desirable advantage in that they can be constructed with great ease in the complex plane. However along with this advantage exists the fact that the characteristic curve which was found by measurement only within a limited frequency range for a network which is not completely known, can be extended for very high and very low frequencies via graphical construction since this curve is always dependent upon the driving function of the circuit element which is directly connected to the measurement terminals.

D. The Encircling Criterium of Strecker

The train of thought presented in this section is concerned with a pure analytical search for the Eigen values of a complicated differential equation or of a system of coupled differential equations; however they form the basis for the following relationship between the characteristic curves of the impedance- and conductance- functions and the increasing or decaying transients of the network.

It should be noted that a stability test, no matter in which manner it is accomplished, must pertain to the completely closed network, and not only to that current loop which encompasses the negative resistance. For example, if one wishes to insert a TD into an antenna, then the network consists of: the antenna with the surrounding region and the receiver input impedance. If the latter were to be changed slightly (for example approx. 20%) the condition of matching would hardly be

altered. However as far as the stability investigation is concerned, a completely different network now exists and can for example become unstable resulting from the alteration. This critical operation behaviour of circuits containing negative resistances rests upon the fact that the desirable effect, as for example deattenuation, obtained by inserting a negative resistance, forces a circuit design which is already very close to the stability margin.

The transients (current time functions) of a purposely chosen simple example as in Fig.1 will be investigated via a system of differential equations. The following solution form is anticipated:

$$i_1 = I_{o1} e^{p_{o1} t} + I_{o2} e^{p_{o2} t} + \ldots\ldots$$

$(p_{o\mu} = \delta_\mu + j\omega_\mu)$

This means that each mesh current: i_1, i_2 etc. consists of a sum of time-dependent current components the number of which is the same as the number of independent energy storage components within the network. As far as the stability consideration is concerned only the time dependencies are of interest, therefore only the Eigen frequencies or transient characteristics: p_{o1}, p_{o2} etc.; the initial amplitudes: I_{o1} etc. are not of interest.

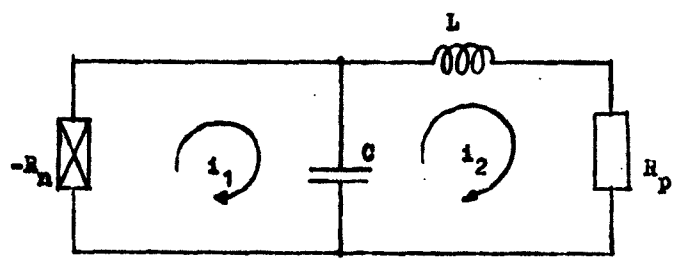


Fig.1

Example for a simple circuit including a negative resistor.

If the voltage drops are summed for the mesh [illegible] in the clockwise direction the following is obtained:

Mesh 1 : $$i_1\cdot(-R_n)+\frac{1}{C}\int i_1 dt \qquad -\frac{1}{C}\int i_2 dt \qquad = 0$$

Mesh 2 : $$-\frac{1}{C}\int i_1 dt - \frac{1}{C}\int i_2 dt + L\frac{di_2}{dt} + i_2 R_p \qquad = 0$$

After the substitution: $i_1 = I_1 e^{p_o t}$ $i_2 = I_2 e^{p_o t}$ has been made in the equations and the latter divided through the function: $e^{p_o t}$

Mesh 1 : $$I_1\left(-R_n + \frac{1}{p_o C}\right) + I_2\left(-\frac{1}{p_o C}\right) = 0$$

Mesh 2 : $$I_1\left(-\frac{1}{p_o C}\right) + I_2\left(\frac{1}{p_o C} + p_o L + R_p\right) = 0$$

In this manner the system of homogeneous diff. equations transposed to a system of algebraic equations in which p_o and the currents are unknown. The resulting equation system is one in which zero is the value to the right of the equal sign; since I_1 and I_2 should not be zero, these equations are only satisfied when the determinent of the coefficient-matrix disappears, then:

$$\Delta = \begin{Vmatrix} -R_n + \frac{1}{p_o C} & -\frac{1}{p_o C} \\ -\frac{1}{p_o C} & \frac{1}{p_o C} + p_o L + R_p \end{Vmatrix} = 0 \qquad (1)$$

or

$$\Delta = p_o^2 R_n L C - p_o(L - R_n R_p C) - (R_p - R_n) = 0 \qquad (2)$$

The relationship (2), is the determing equation for the n-Eigen frequencies: p_{o1}, p_{o2}, $p_{o\mu}$ etc. and will be called the characteristic equation. In respect to the above example a second order polynomial is obtained and only two solutions: Eigen frequencies p_{o1} and p_{o2} exist for which the polynomial can have the value zero, and pertain then only to two energy storage devices in the network.

The method of transposing the system of coupled diff. equations to a system of algebraic equations instead of setting up the characteristic equa. in the usual manner has been done intentionally here in order to be able to make use of the matrix order scheme. In this manner multi-termed networks can be investigated in a digestible manner, for example by using the many transformation rules for equivalent matrixes thus considerably simplyfying the calculation procesdure for the determinent. In addition some general pure algebraic stability test methods exist, which rest upon the coefficient matrix set up in (1) (for example the determinent criterium of Hurwitz [3]). Also it is common practice to obtain the derivation of impedance and conductance functions from such mesh equations or matrixes, and in this manner the relationship between the characteristic equation and the network functions (impedance, conductance, transformation values) can be written. For an nth-tern network a polynomial of the nth-order is obtained as the characteristic equation:

$$a_n p_o^{\,n} + a_{n-1} p_o^{\,n-1} + \cdots\cdots\cdots\cdots a_1 p_o + a_o = 0 \qquad (3)$$

and it is now not possible to calculate explicitly the n-solutions which are the n-Eigen frequency values.

This difficulty can be bypassed in the following manner:

Actually it is not required that the numerical value of each Eigen frequency:

be known, since we are only interested in determining, if the net ork is stable or not and it seems to be unimportant to know exactly in what respect the corresponding network is unstable. This means that it is not required to know the exact time function with which a transient decays or increases in amplitude. Therefore it is sufficient to know, if any one of the n-solutions "$p_{o\mu}$" of the characteristic equation poses a positive real part "σ_μ". If this condition does exist, then the current component: $I_{o\mu}e^{(\sigma_\mu + j\omega_\mu)t}$ climbs above all limits with increasing time: however the other current components which have a negative real part in the exponent decrease towards zero with increasing time "t".

Accordingly, the initial current amplitudes "$I_{o\mu}$" are also unimportant and need not be determined here; they could have an arbitrary small value for example: they could describe the noise amplitude of the circuit component itself. The exponential increase as a function of time in reallity determines the dynamic behaviour of the circuit. It can occur that the initial transients may develop into a steady state oscillation (oscillator) resulting from the non-linear behaviour of the circuit component, usually of the negative resistance itself.

In order to answer the decisive question above: "Does the characteristic equation have at least one solution with a positive real part?" The following treatment is made: The magnetude "p_o" of the polynomial (3) is substituted by a general complex number "p" and the following characteristic function is obtained:

$$a_n p^n + a_{n-1} p^{p-1} + \cdots\cdots\cdots\cdots a_1 p + a_o = F \qquad (4)$$

This polynomial is now considered as the transformation function for transforming from the complex p-plane to the complex F-plane. Actually only the imaginary axis of the p-plane is to be transformed, thus:

$$a_n (j\omega)^n + a_{n-1} (j\omega)^{n-1} + \cdots\cdots\cdots a_1 j\omega + a_o = F \qquad (5)$$

and a definite curve is obtained in the F-plane (see Fig. 3). Theoretically the polynomial in (5) can be decomposed to the following factors:

$$(j\omega - p_{o1})(j\omega - p_{o2}) \cdots\cdots\cdots\cdots (j\omega - p_{on}) = (F - 0) \qquad (6)$$

Each of the linear factors $(j\omega - p_{ou})$ corresponds to a vector in the p-plane which is to be considered as existing between the Eigen value p_{ou} to the movable point $j\omega$ on the imaginery axis (see fig.2). If the network is stable, which means that all Eigen frequencies lie on the left side of the p-plane, then each n vector rotates about the angle $+\pi$ as ω takes on all the values between $-\infty$ and $+\infty$ in this order. The rotation angle sum of all the n linear factors on the left side of equation (6) must however be equal to the rotational angle of the (F-0)-vector on the right side of the equation.

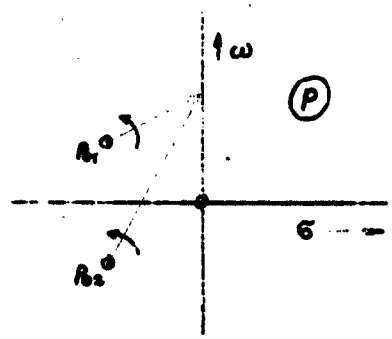


Fig.2
...ers in the p - plane.

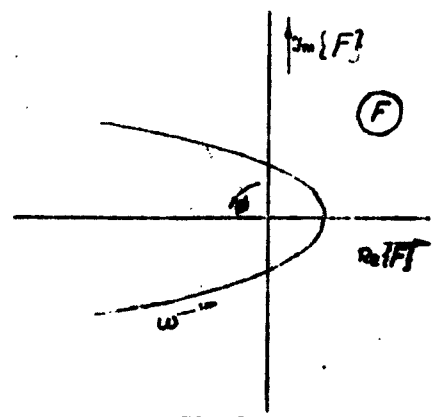


Fig.3
The plotted curve of the aiding F - Funktion.

However the actual position of the Eigen values are not known in the p-plane but the transformation of the imaginary axis of the p-plane into the curve $F(\omega)$ is available by equation (5). However since the order of the polynomial is specified by (5) and thereby also the number of the possible Eigen frequencies, or linear factors of the separation as in (6) it can now be

said: A vecotr (F-0) which exists between the origin of the F-plane to the points on the curve $F(\omega)$, will rotate about the origin with the angle $\phi = +n\cdot\pi$ if the circuit is stable, which means that all the Eigen frequencies have negative real parts (see fig.2 + 3 for n=2). However if instability exists, which means that at least one Eigen value is located in the right side of the p-plane, then one of the n possible vectors does not exist in the left side of the p-plane; thus its corresponding rotation factor $+\pi$ is missing and the rotation factor $-\pi$ of the corresponding vector causes its appearance in the right side of the p-plane (see fig.4).

Thus a single Eigen frequency having a positive real part prevents the maximum possible rotation angle of the (F-0)-vecotr $\phi_{max} = n\cdot\pi$ by the factor 2.

Therefore the results yield:

$$\begin{aligned} &\text{the circuit is stable for } \phi = n\pi \\ &\text{the circuit is unstable for } \phi < n\pi \end{aligned} \qquad (7)$$

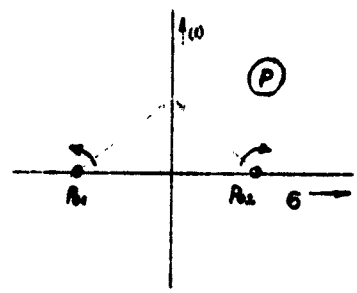


Fig.4
Seros in the p-Plane

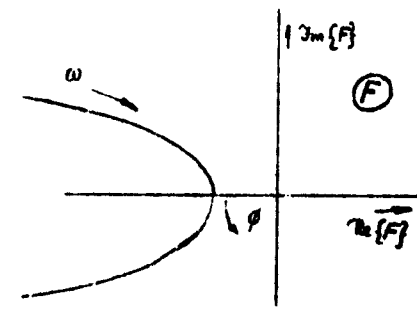


Fig.5
The plotted curve of aiding F - Funktion.

In conclusion it should once again be noted that these stability checking procedures may only then be applied when the network structure is known. The characteristic curves which are depicted in fig. 3 + 5 describe an aiding function: $F(\omega)$, which has no meaning other than being an helping function and also can not be determined by circuit measurement.

E. The Relationship beween the Characteristic Equation and the Impedance or Conductance Functions of a Network

In the following it will be shown that the characteristic equation (5) is contained in each impedance and conductance function. In addition the limitations in unsing the characteristic curves of such functions in respect to the stability check, which was developed in the preceding section, will be shown.

First of all a simple network as in fig.6 will be investigated in order to determine the relationship between the Eigen frequencies of a network and the respective impedance or conductance functions. The network of fig.6 contains a lossless parallel resonance circuit. If in the following relationship:

$$i = u \cdot Y_b \; ^{+)}$$

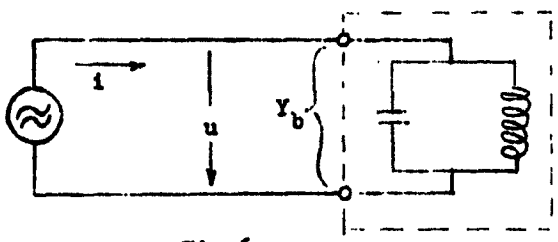


Fig.6
Example for a circuit having seros only

a finite voltage exists at the network terminals even for an infinitely small current "i" (open ckt. terminals) then $Y_b = 0$. For the above example this condition can easily be visualized: For the Eigen frequency ω_o a voltage can exist at the terminals of a lossless tank circuit without requiring that a current be induced into the network from without. This means that the Eigen frequencies of the network are obtained from the requirement: $Y_b = 0$. For the above example the following is valid:

$$Y_b = pC + \frac{1}{pL} = \frac{p^2LC + 1}{pL}$$

and from $Y_b = 0$ or $p^2Lc + 1 = 0$ the following is obtained:

+) the subscript "b" means that the corresponding conductance pertains to a brach of the network.

$$p_o = \sigma_o + j\omega_o = \frac{1}{\sqrt{-LC}} \quad \text{and} \quad \omega_o = \frac{1}{\sqrt{LC}}$$

(for a lossless tank circuit: $\sigma_o = 0$)

Each impedance, conductance and transformation function consists of ratio of two polynomials when considered analytically:

$$Y_b = \frac{a_n p^n + a_{n-1} p^{n-1} + \cdots\cdots a_1 p + a_o}{b_m p^m + b_{m-1} p^{m-1} + \cdots\cdots b_1 p + b_o} \qquad (9)$$

Therefore, if the Eigen frequencies can be calculated from the requirement: $Y_b = 0$, then the nummerator polynomial in (9) must be identical to the characteristic equation (3) of the circuit, as compared to the previous section where they were obtained from a system of differential equations. (For an impedance function "Z_b", the polynomial of interest is found in the denominator.) In this respect it is unimportant as to which terminals the conductance function (9) pertains since the nummerator is identical for all Y_b found in the network. Therefore when the impedance or conductance function can be presented in algebraic form as in equation (9), the characteristic equation can be recognized allowing for the use of the encircling criterium of(7).

Setting up the analytical conductance function is somewhat simplified by means of a continued fraction corresponding to an arbitrary network branch as compared to setting up the system of coupl·d differential equations and calculating the determinent of the coefficient matrix.

Before the encircling criterium can be applied in a merely traphical manner to characteristic curves, (actually this goal is the only one of practical interest) the meaning of the denominator polynomial of equation (9) should be given:

If a finite current is measured at the terminals of fig.7 even though the voltage is infinitely small in amplitude (input terminals of fig.7 short circuited) then in the relationship: $i = u \cdot Y_b$ of the conductance Y_b must have the value ∞ , or the denominator polynomial of equation (9) must become zero. The

Eigen frequencies are obtained from this relationship of the network which is altered in such manner: The denominator polynomial of a conductance function Y_b (or the numerator polynomial of a impedance function Z_b) is the characteristic equation for the network which is short circuited at its terminals (for Y_b or Z_b).

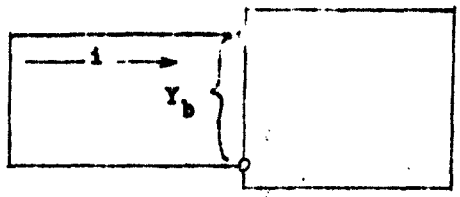


Fig.7
Example for a circuit having poles .

In order to make use of the previously mentioned stability check, the degree of the numerator polynomial must be knowu; this knowledge cannot be obtained from the shape of the characteristic curve. However it is known that for all the impedance, conductance and transformation functions, the numerator and denominator polynomial differ at the most by one degree , which means that they differ from one another by at most one Eigen frequency or one vector in the p-plane (see fig.2 + 4). This relationship is independent of the number of the reactance components which the network contains, thus independent of the magnitude of "m" and "n" in equation (9).

Previously it has been mentioned that the complete rotation angle of the function (3) or (4) is $n \cdot \pi$ when the variable ω passes through the values from $-\infty$ to $+\infty$ and the network is stable, which means that all the Eigen values lie in left side of the p-plane. However due to the fact that $\frac{1}{e^{j\phi}} = e^{-j\phi}$ the rotation portion of the denominator polynomial has the opposite sign as compared to the numerator polynomial and since the two polynomials can only differ in their degree by the value of one, the complete rotation of a (Y_g-0)-vector can only have the following values: $\phi = -\pi$, $\phi = 0$, or $\phi = +\pi$.

Fig.(8) shows these three possible cases; they differ from one another in that either the dregree of the numerator or denominator polynomial is larger or both have the same magnitude. The circuit differs in that the network structure directly behind

the terminals differs and the corresponding characteristic curves differ in their end points for the frequency $\omega = \pm\infty$.

At this point a limitation must be made: the example of fig. 8c which is a conductance function having a higher degree in the denominator polynomial, is to be excluded in the following considerations. This particular starts with a series component whereas the conductances Y_b, which are to be considered here, are always to be measured parallel to branch. This limitation is not serious since the characteristic Y_b-curves, which serve for determining circuit stability, may correspond to any arbitrarily chosen terminal pair up to this point. Also for networks in which the structure is not completely known, a terminal can certainly be found at which a branch, namely an arbitrary parallel component as for example a parallel capacitance, exists.

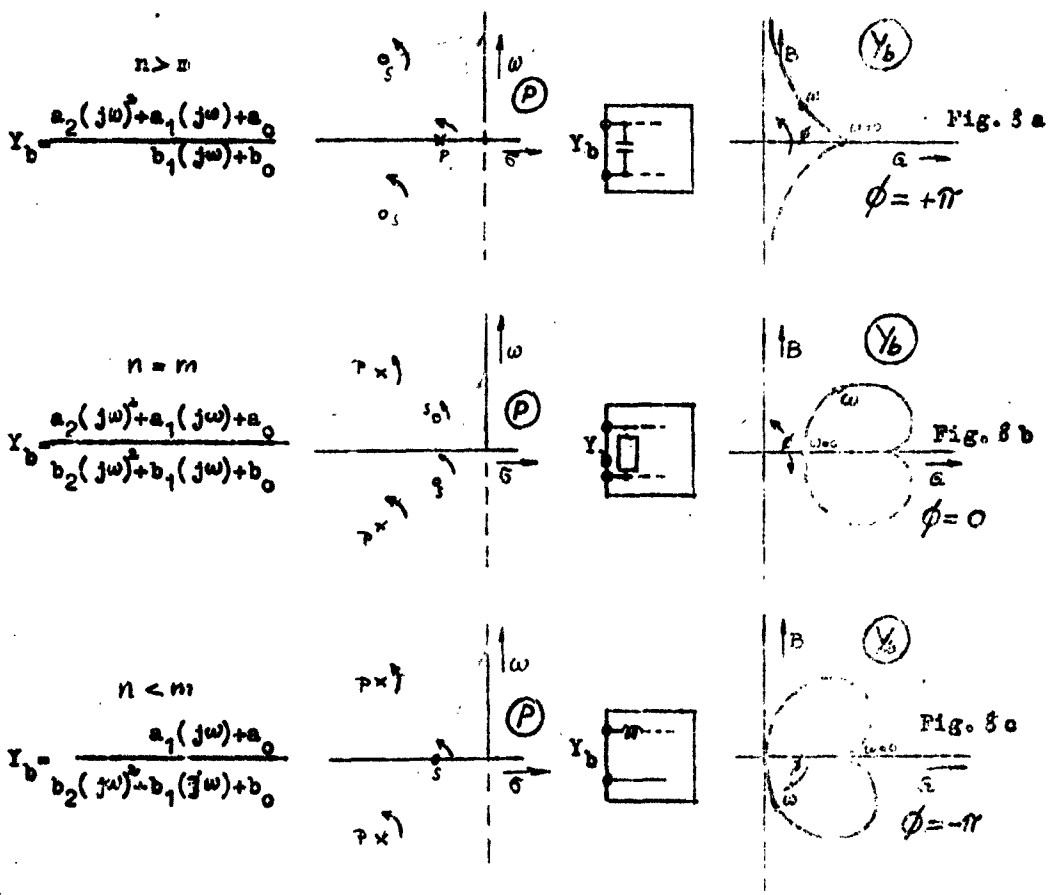


Fig.8 : Poles and zeros of a network with the corresponding admittance curves.

Therefore it can be said that the (Y_g-0)-vectot which is to be considered as existing between the origin and a movable point on the Y_b-curve, can only rotate by the angle $\phi = +\pi$ or $\phi = 0$ if the network (see fig.8) is stable, as the vector point passes along the characteristic curve for all frequencies $\omega = -\infty$ to $\omega = +\infty$ in this order.

Now is to be assumed that the network is unstable; thus the numerator of the Y_g-function possesses at least one zero in the right side of the p-plane whereas the denominator has only Eigen values (for the present consideration) in the left side of the p-plane as depicted by fig.9a + 9b. Since the vector in the right side of the p-plane gives a negative rotation component, the rotation angle sum of the passive conductance function given above, cannot be maintained. The angle ϕ of fig.9 attains the values: $\phi = -\pi$ or $\phi = -2\pi$ even for a single increasing Eigen frequency these values cannot exist for any branch-conductance Y_b of a stable network (fig.8).

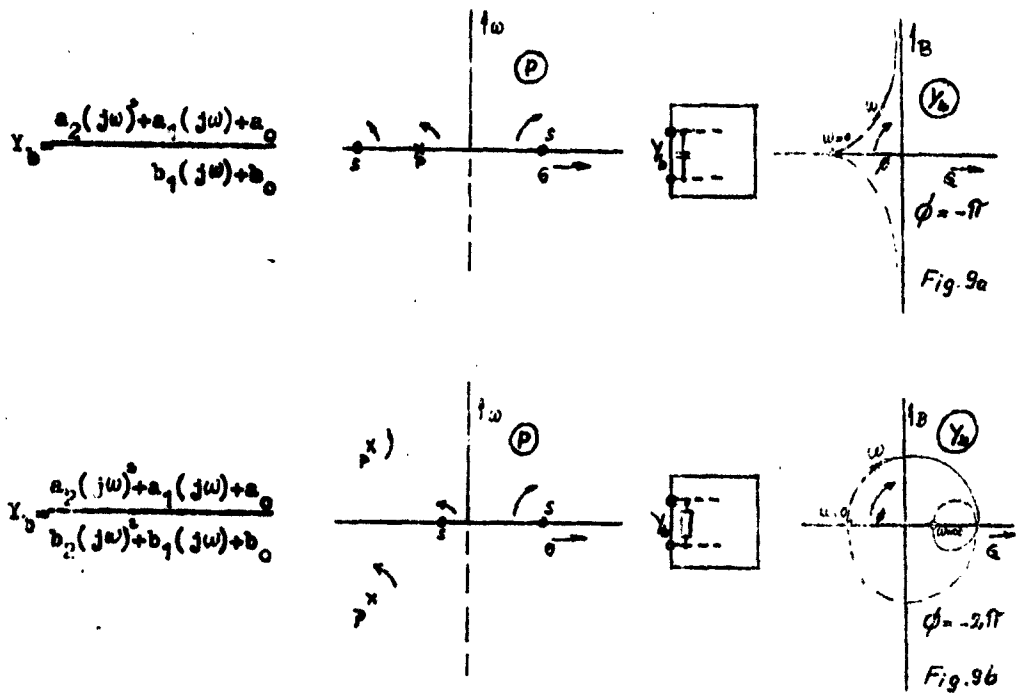


Fig.9 : Poles and seros of a network with the corresponding admittance curves.

For the preset requirement for fig.9, namely that the circuit is stable for the condition of short circuit at the terminals of Y_b, the stability criterium can be stated in the following manner: The network is stable, if the rotation angle of the vector which is pictured as existing between the origin and an arbitrary point on the characteristic curve of an arbitrary branch conductance Y_b is not negative.

At this point it seems that an objection can be made; namely: What significance does the stability criterium have when it also requires the experimental determination of a specific stability (with short circuited terminals)? It should be reminded here, that the purpose of the stability check is not only one of determining whether the particular network in question is stable, (this could also be determined via experiment) rather the principal purpose of this method seems to be the determination of definite arrangements which allow for stabilizing the network.

Since the choice of the measurement terminals is completely free for the above mentioned criterium, and no requirements of the network (for example concerning the number of the negative resistances contained therein have not been set,) it seems theoretically possible, that a terminal pair exists at which first: a short circuit does not cause instability, and second: the measurement equipment does not effect this condition (as could be caused by the imput impedance of the measurement equipment) since the measurement at an oscillating network cannot yield data which can be evaluated. Later, this general but insufficient formulation of a stability criterium will once again be referred to but dropped for the present, since the required limitations mentioned previously in this respect cannot be guaranteed when an absolutely reliable stability test is to be accomplished for a complicated circuit.

Since experience has shown, that an unstable network remains unstable for most cases even when a network branch is short circuited (actually very few branches of the network are readily available for measurement) an impedance or conductance function cannot enable a clear stability examination when these general requirements are considered.

The reason for the above statement can be obtained from the following train of thought: If the denominator of example in fig.9 had also had an Eigen value in the right side of the p-plane (unstable under the conditions of short circuited terminal pair) then the negative rotation component of the numerator polynomial would have been compensated by the corresponding component of the denominator polynomial, and the rotation angle check of the Y_b-function would have given the same result as the case for a stable circuit (fig.8).

Therefore it is quite clear that the previously developed rotation-angle-check is insuffiecient for such cases. Certainly the investigation via measurement of such network is also fruitless since, as has already previously been mentioned, the measurement of an oscillating network is of no value. However if the characteristic curve of such a circuit had been constructed in the resistance or conductance plane, then the instability could have been predicted by means of analizing the behaviour of such unusual characteristic curves. For example: if the characteristic completely remains in the right side of plane and contains only counter clockwise turning curvatures. Also the correlation of specific regions in respect to their boundary curves as obtained from conformal mapping principles can successfully lead to determination of an instability in that one determines whether the origin of the Y_b-plane can be mapped into the region of the p-plane having $\sigma > 0$. Additional criterions of this nature is being intentionally ommitted here since a desirable system in this respect could not be obtained as of yet and the majority of such criterions only lead to an instability statement; however no difinite conclusion is reached as to the stability.

F. Possibilities for a Clear Stability Determination

From the considerations developed in the preceding section and especially from the determination of the influence of the denominator polynomial, the following two restricted assumptions which allow for a clear and meaningful stability check via measured

or constructed impedance or admittance curves, appear to be necessary:

1. The circuit contains only one negative resistance.
2. The measured or geometrically constructed characteristic curves, which are used for the stability check, refer to those circuit terminals, between which the negative resistance has been inserted, (therefore no longer in an arbitrary network branch).

In this manner it is guaranteed that the denominator polynomial of the test-function Y_b can never have Eigen values in the right side of the p-plane, since the network which is short circuited at those terminals is definitely passive. The only existing negative resistance would have no effect due to the short circuit, and the statements made for fig.8 for a stable circuit in respect to the rotation angle of the $(Y_b - 0)$-vector or the given values pertaining to an unstable circuit for fig.9 are valid. The associated requirement, that the test function must pertain to a branch of the network (in contrast to a terminal pair which would exist due to a junction separation) is without doubt fulfilled by the above requirement No.2 and retained herein.

One can summarize in the following manner:
One considers that a vector exists between the origin to the locus of the $Y_b(\omega)$ function (either measured values or geometrical construction for the only network terminals, which contain the negative resistance,) then the circuit is then stable, when this vector does undergo a clockwise rotation; thus the rotation angle ϕ either has the value 0 or $+\pi$.

(For the sake of clarity, these investigations were carried through only for branch-conductance values. The same test criteriums are also valid for a branch bisection impedance (impedance between the two resulting terminals obtained by opening a network branch): thus the branch containing the negative resistance must be opened and the impedance at the two resulting new terminals must be measured. Due to the desire of obtaining practical and

and convenient measurement techniques, this test function is somewhat unsiutable. When branch-impedances $Z_b = \frac{1}{Y_b}$ are used then the sign of the given angle value changes .

Before the practical signifacance of the limiting assumptions is to be discussed, the above mentioned stability criterium should be transformed to a suitable form. Since the characteristic curves which are to be evaluated, exist in an unusally large frequency range, they can continuously lie further away from the point of matching (operating frequency) by spiraling about this matching point with varying radius. Therefore the presentation of curves in the Smith diagram should be set in preference to the previuos presentations in the cartesian coordinate system. However a portion of the impedance and conductance characteristic curves for a circuit containing a negative resistance, pass through the negative portion of the plane; the above inferred advantage (in the unity circle) of using the Smith Chart also has the large disvantage that the negative plane lies outside of the unity circle in the negative plane for the same transformation ($Y_{tr} = \frac{Y}{Y + Y_0}$ and extends to infinity.

This difficulty can be bypassed by transforming the test-function Y_b and the test point (origin). If one considers the fact that the conductance at the terminals of the negative resistance always has the form: $Y_b = Y - \frac{1}{R_n}$, then the following variation of the test vector is possible:

$$(Y_b - 0) = (Y - \frac{1}{R_n} - 0) = (Y - \frac{1}{R_n}) \quad \text{see Fig 1o}$$

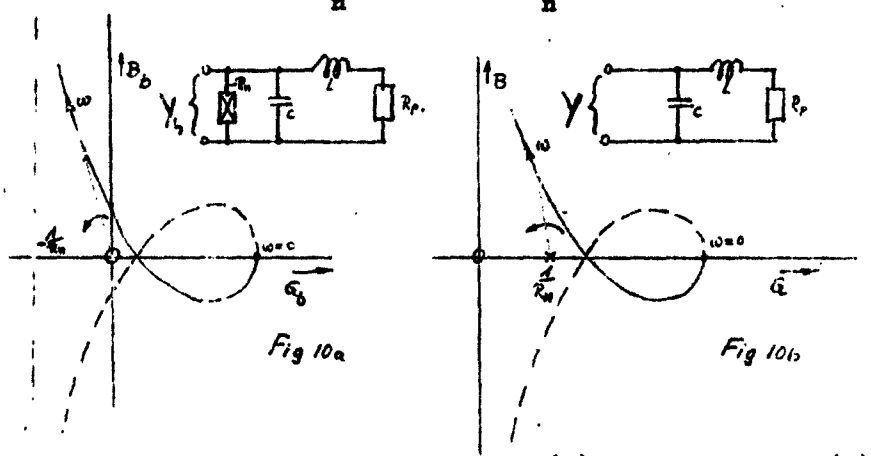


Fig.1o Transformation of the curve $Y_b(\omega)$ into the curve $Y(\omega)$ for the sake of a suitable stability test.

This means that a new conductance function Y exists, which replaces the previously used test function Y_b, or the vector which was drawn between the origin and the locus of $Y_b(\omega)$, is replaced by the new test vector, now considered to lie between the point $\frac{1}{R_n}$ to the locus of $Y(\omega)$. (fig. 10).

The new test function "Y" is that conductance, which remains at the respective terminals, when the negative resistance is removed . Therefore a pure passive conductance function remains and the corresponding characteristic curve can never exist in the negative half plane.

Therefore not only is the practical use of the Smith Chart assured, but additional practical advantages are obtained:

The self excitation of a circuit is now no longer of a disturbing nature when experimental investigations in the form of measurements are undertaken, since the circuit can only then become unstable when the negative resistance is connected. If the network contains other negative resistances, then the above criterium can be applied, (if even the first of the preset requirements is violated) if the measured characteristic curve of the test function verifies the condition, that the network is passive.

Characteristic curves of passive circuits correspond in one respect to the matching considerations of known geometric curvatures, (thus an actual measurement is superfluous in many cases) and correspond in the other respect to the firm limitations of their curvature concerning the rotation sense of a vector which is pictured as extending to such characteristic curves.

Now in consideration of the previously mentioned condition that a stable network is remarked by the fact, that the vector, which is considered as being drawn from the point $\frac{1}{R_n}$ to the points on the curve $Y(\omega)$, may not posses a clockwise rotation sense, and on the other hand, H. Wolter [4] has proven, that such a vector my not posses a counter clockwise rotation sense if the

network is passive, it can readily be concluded, that the point $\frac{1}{R_n}$ may not be encompassed by the test curve if the circuit is to be stable.

Now the impedance function can once again be introduced as the equivalent test function: if the point $\frac{1}{R_n}$ in the conductance plane is not encompassed by the characteristic curve "y(ω)", then the point R_n is also not encompassed by the characteristic curve Z(ω) in the impedance plane, since in the case of reciprocal transformation the correlation of points and regions remains the same. Fig.11 shows the curves in the impedance and admittance planes for some examples of stable and unstable circuits.

Now the stability criterium can be stated in its final form:

> "If a negative resistance $-R_n$ is to be inserted into a passive network and stability is to be guaranteed, then the characteristic curve for the immittance at the foreseen terminals for tunnel diode insertion must not encompass the point $\frac{1}{R_n}$ in the conductance plane or the point R_n in the impedance plane."

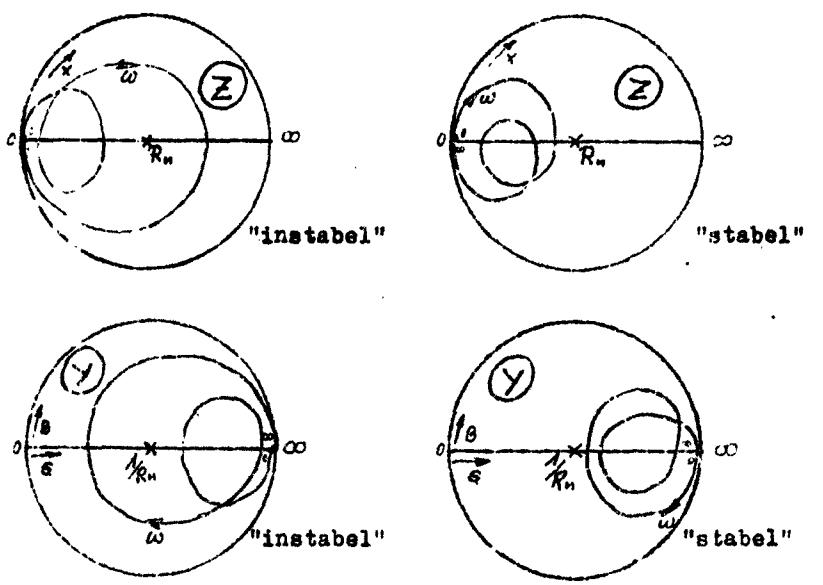


Fig.11 Stability test by impedance and admittanz curves. The right examples are stabel, the left ones are instabel.

C. Discussion of the Limitation Assumptions

It should be reminded that the reliability and clarity of the previously mentioned simple stability criterium of the measured or geometrically constructed characteristic curves was accomplished primarily by making the two following important limitations:

1. The circuit contains only one negative resistance. (However more neg.res.may be contained in the circuit, if these additional ones are directly parelleled by a larger positive conductance, this condition hardly seems to be of technical interest)

2. The measured or geometrically constructed characteristic curves which are used for the stability consideration, must apply to those terminals of the network, between which the neg.res.is to be inserted.

In accordance with the practical application desired, either as a two pole amplifier or as the case max be, for obtaining special impedance functions, these requirements may become difficult and sometimes impossible to fulfill. In the following these investigations will be conducted for the amplication behaviour of the neg.res.amplifier, since this is a completely discribebal application goal.

In respect to a two pole amplifier the first previously mentioned requirement does not present a limitation since an arbitrary high amplification may be achieved in one stage. Since the present state of the art of four pole amplifiers for frequencies below the microwave range are at least equivalent in performance and less critical as far as stability is concerned, in respect to tunnel diode application a low-noise pre-amplifier for microwaves is to be considered here. A corresponding two pole preamplifier can without doubt be used to achieve a stable operating amplification of 2o dB. In addition it should be noted that the noise figure of the directly connected convential microwave receiver (connected directly behind the T.D.preamp) becomes negligible as compared to the noise figure of the T.D..

the use of more than one T.D. is not necessary in this case.

If in addition the "Gain Bandwidth Product" is to be increased via series connection of several stages(having displaced tank circuit frequies) then these stages must definitely be one-way buffered from each adjoining stage by using a non-reciprocal four pole (uniline, Gyrator). If this were not done, the end result would be a multiple parallel connection of tank circuits and T.D.s which behaves in the same manner as a single tank circuit. The non-reciprocal four poles breaks the circuit down into several component networks without reverse inpedance behaviour. Each component network, which thus only contains one T.D., fulfills the above mentioned requirements, and can therefore be clearly investigated.

The desire for inserting several T.D.s into a circuit is then always desirable, when available power of a single element (approx. 10 μW for Ge-TDs) resulting from the minute voltage regulation region, is insufficient. (For an oscillator application this is obvious. It should be shortly mentioned here, that also for this application, which refers to an intentially unstable network, a stability is definitely worthwhile, since an undesirable sharp shift or change of frequency must be avoided.)

The direct parallel connection of several T.D.s, which fulfill the above limitations, however is without practical significance, since T.D.s having an arbitrary low resistance can be produced. However the possibility of obtaining stability becomes continuously more critical as the resistance of the TD is decreased. In this sense a series connection of low-resistance T.D.s appears to be suitable; It seems, that a negative resistance is then obtained, which has a factor n (n = number of T.D.s) larger voltage regulation range. However this arrangement of real negative resistances is not possible in principle with T.D.s, since a relatively complicated network exists allready when tunnel diodes are connected in series due to the internal reactive components of the T.D. and a single negative

resistance can never be obtained in this manner. Such series circuits are basically unstable (even when the actual network consists of a simple component for example: largest possible ohmic conductance) if one expects that a suitable bias voltage distribution exists among the individual elements. In the case of individual bias voltage supplies, a series connection is basically possible and can be tested in principle by the above mentioned criterium.

In conclusion it can be noted that the T.D. practically does not fall under any limitations for a single active element when considered for the application as a low-noise small signal amplifier for microwaves (this is the most important field of application for the T.D.).

An objection to the second requirement (which pertains to checking the characteristic curve at the terminals of the negative resistance) can readily be made since these terminals are not accessible since they are located approximately 10 to 100 Å apart from oneanother within the semi-conductor crystal. Whereas the reactive components of the T.D. may be neglected for circuit considerations below 100 Mc, these internal reactive components such as the parasitic socket and lead reactance may not be neglected for the stability consideration. These parasitic elements as dipicted in Fig. 12 have been reduced to extremely small values via technology; however the measurement of the same can be accomplished with sufficient accuracy by using the methods [5] which was especially developed for this purpose.

Therefore the characteristic curve $Y_e(\omega)$, measured at the location of planned T.D. insertion, can be transformed to the suitable test curve $Y(\omega)$ by means of a four pole transformation, see Fig. 13.

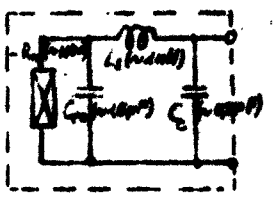


Fig.12
TD equivalent network.

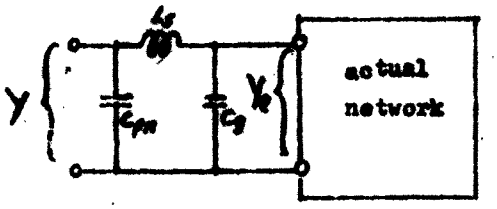


Fig.13
Transformation of the measured admittance of the actual network into the suitable test funktion Y.

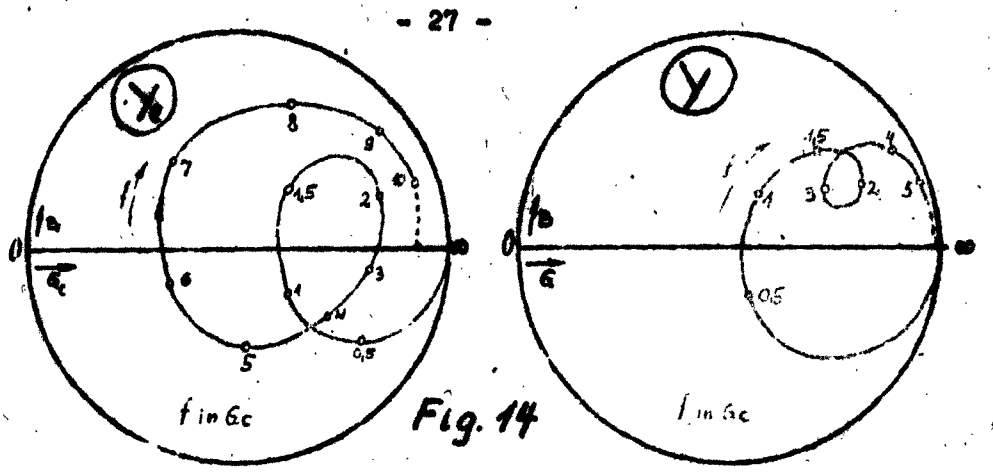


Fig. 14

Such a transformation has been accomplished in Fig. 14; the circuit is stable.

For practical applications this method has the following disadvantages: It has already been explained that the purpose of the stability test is not only that of determining whether the characteristic curve is suitable, but rather this test should also enable the determination of suitable arrangements which aid in obtaining a suitable change in the curve. The reactive components of the equivalent T.D. circuit of Fig. 12 and 13 cannot be completely freely chosen, since this can only be achieved by sorting out the T.D.s accordingly to the desired parameters. However the characteristic curve of very few circuits transformed by the equivalent reactive circuit of the T.D.

in such a way, as to yield a suitable change of the characteristic curve. The change must be accomplished in the passive network itself. However due to the four pole transformation circuit existing between the negative resistance and the passive network, it is not directly possible to determine the desirable Y_e-curve in respect to a stability consideration by observing the Y-curve.

Therefore there remains the desire to be able to make a stability consideration directly at the terminals of the actual circuit. By means of a suitable change of the test criterium this desire can be taken into account.

Until now the stability check rested upon determination and the evaluation of the relationship between the characteristic curve and the test point. If it is desired to transfer the checking relationship from the real test point $\frac{1}{R}$ or R_n to the frequency dependent input impedance $Z_n(\omega)$ of the T.D., then the new corresponding test method consists of: thoroughly investigating the relationship between the input impedance Z_e of the circuit and the characteristic impedance curve of the TD in order to dtermine, whether mutual curve shapes and intersection points exist.

In this respect a characteristic impedance curve (will called a boundary curve in the following) exists via imaging the impedance (or conductance) curve of the T.D. in Fig. 15. This boundary curve is the locus of all impedances which transform into the point R_n for the respective frequency parameter. The impedance curves $Z_e(\omega)$ of the circuit to be tested, may not intersect the boundary in this backward-diagram for the same frequency parameter, but may posses an arbitrary shape as a function of frequency below the boundary curve. Now in respect to the criterium expressed at the end of the preceding section, a circuit is not only then unstable when the test curve intersects the test point (this would be the specific boundary case between stability and instability) but more generally expressed: the circuit is unstable when the test curve encompasses the test point. A necessary for an encompassment (encircling) is that the characteristic curve intersects the real axis. In the back-

ward-diagram the last requirement expressed is that the characteristic curve to be tested may not intersect any parameter curve (broken curves in Fig. 16) at a mutual frequency parameter. This is required since all points on each curve is transformed into the real axis at the respective frequency via the transformation four pole (see Fig. 13).

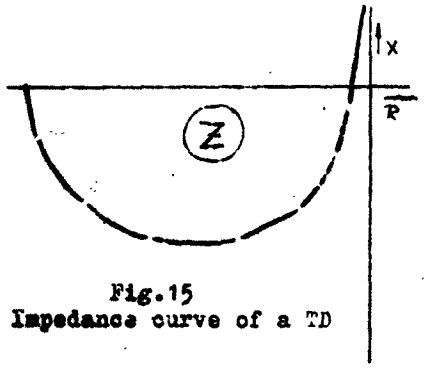


Fig.15
Impedance curve of a TD

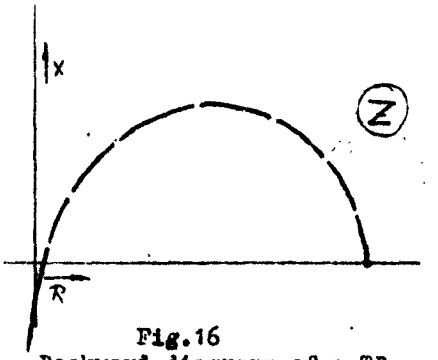


Fig.16
Backward-diagramm of a TD.

Thus the stability criterion in the backward diagram is the following:

The circuit is stable when:

1. the characteristic curve to be tested $Z_e(\omega)$ (or $Y_e(\omega)$) must remain completely below the boundary curve or
2. the characteristic curve to be tested may intersect or bound the boundary curve, but only under the condition, that no common point exists for the same frequency.

Fig. 17 a shows an example; at a mutual frequency of 1.8 Gc an intersecting point exists and the circuit is unstable. In Fig. 17b the characteristic curve has been changed in such a manner, that no frequency value common to the characteristic curve and family of parametric curves exists outside of the boundary curve.

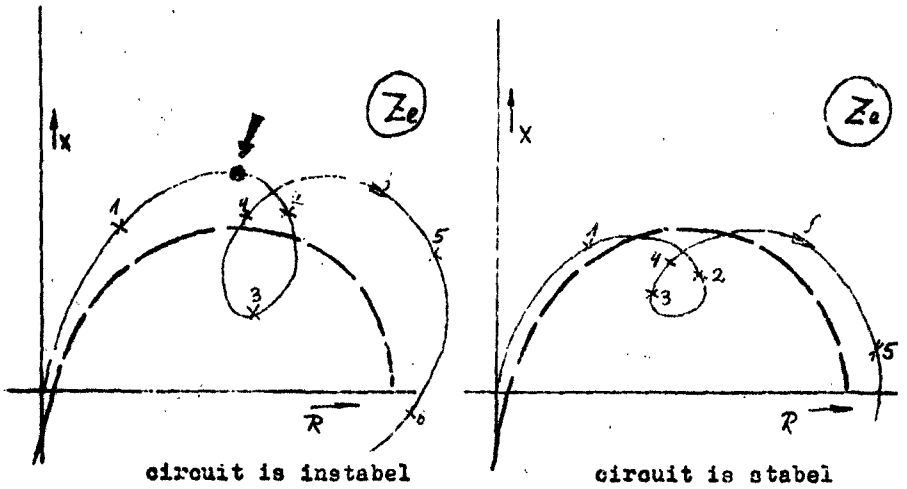


Fig.17
Stability check in the backward-diagramm.

E. Stabilization of Tunnel Diode Circuits.

Since an unstable circuit does not perform the originally design function (in this case the T.D. appears to have considerably higher negative resistance) the recognition of the stability considerations must be accepted as fundamental designing principles of a network with negative resistances.

From the fact, that the characteristic curves for the frequency $\omega = 0$ always begins at the real axis, and must also end on the real axis for the frequency $\omega = \infty$ and in addition, since the curves considered here can only follow a clockwise curvature, and finally from the knowledge of the reactance (barrier capacitance) directly adjacent to the negative resistance, an advantageous insight as to which circuits are stable in principal and which are principally unstable is achieved.

(In the following the use of the backward diagram will be avoided, since it is suitable for concrete investigations, but

is less suitable for discussing principal phemomena. The characteristic curves will once again be discussed in respect to the test point R_n).

First the so called "DC-current stability" will be observed, for example: this arises from the known requirement that the input impedance of the bias supply (Z for $\omega = 0$) must be smaller than the magnitude of the negnative resistance; Fig. 18 shows the characteristic curve. Two of its characteristics are completely sufficient for the stability consideration: it begins at $R_i > R_n$ for $\omega = 0$ and ends at the point $Z = 0$ due to the barrier capacity. These two end points of the, (in all cases) closed characteristic curves, lead without deviation towards an encircling of the point R_n, independent of any additional circuit characteristics, which means, independent of how many and how large the characteristic curve loops may be for the finite frequencies. The circuits is unstable for $R_i > R_n$.

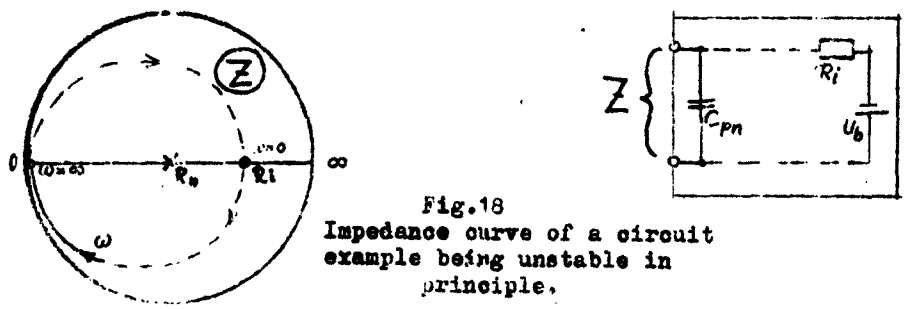


Fig.18
Impedance curve of a circuit example being unstable in principle.

As an additional example of a basically unstable circuit, the wide band matching principal via loop formation about the matching point of the impedance curve as used in high frequency circuits will be given: If a network (for instance an antenna) is to be matched to the real imput impedance of the generator over a large frequency range, then the charachteristic curve of the imput impedance must remain in the immediate vicinity of matching ($|Z| \sim R_i$) for each frequency in the desired band. In practice this is accomplished via matching and compensation

circuits and gives the characteristic curve of Fig. 19 a characteristic looping behaviour.

In the same manner the desired effect of the negative resistance in a passive network (deattenuation, amplification etc) is always expressed through the magnitude of the numerical relationship between the negative resistance and the magnitude of the respective parallel impedance insertion, thus through $|Z| - R_n$.

If this effect is to remain wide band in nature, then analogous to the above mentioned matching phenomena, the value $|Z|$ or the characteristic curve for $Z(\omega)$ must remain in the immediate vicinity of R_n throughout the largest possible frequency range.

(The expression "matching" is not exact as used here. In one respect the ideal situation does not at all exist when $Z = R_n$, and on the other, a negnative resistance can never be matched to a positive resistance as far power transmission is concerned.)

The stability theory forbids the loopping principal as depicted in Fig. 19, since the forced clockwise curving loops would encircle the test point. The characteristic curve in Fig. 20 does not contradict the stability requirement.

These pure qualitative observations already allow for recognizing the circumstance, that the desirable effect, realized by the negative resistance, can only be achieved in a narrow band region. It can also be concluded, that a complicated circuit, which tends to develop several loops, has little chance of giving a stable network when combined with a negative resistance.

Experience, resulting from practical investigations of T.D. circuits, has shown, that also those circuits which should be stable when analyzed according the stability checking procedures mentioned, actually were at first not stable when the corresponding circuit was built in practice. Characteristic curve measurement or determination of the frequency of oscillation have shown, that this instability existed considerably outside the operating frequency and did not seem to be related to the regular

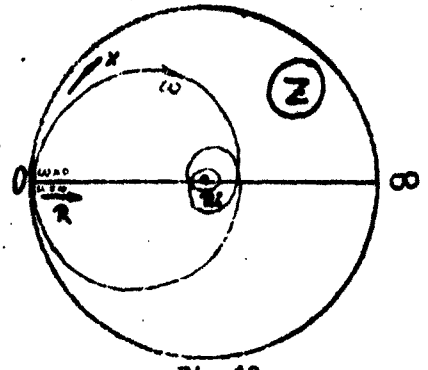


Fig.19
Impedance curve of a circuit example being unstable in principle.

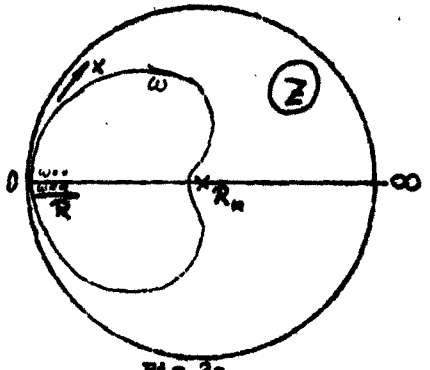


Fig.2o
Impedance curve of the stable circuit.

behaviour of the inserted circuit components nor could it be removed by changing these components. This situation is also encountered in the simplest circuits; it is due to the reactance behaviour of the parasitic elements which are at first unknown for a particular circuit design and therefore could not be considered for the stability test.

If the universal application of the T.D. considers the unusual wide band behaviour of the negative resistance as a general advantage, then the disadvantage, that this wide band behaviour forces a stability check for those frequency regions in which the circuit is unknown and uninteresting, is quite evident. In practice it is hardly probable that a circuit, which has readily been adjusted for the operating frequency range by varying all incorporated components, suffices the requirements in respect to the impedance curve also for the unlimited region outside of this range.

However it is possible to influence the characteristic curve via a freely chosen supplementary circuit, in such a manner, that the stability of the network alone is valid within the operating frequency range, whereas outside the operating range the supplementary network (two pole stabilizer) specifies the stability behaviour.

The function of the supplementary network may also be included with the T.D. characteristics (this network must be inserted in the immediate vicinity of the T.D., for example at the T.D. socket) and the circuit contains a new negative resistance, which only exists within the operating frequency range; outside this range the neg.res. is compensated by a large real conductance.

Fig. 21 shows a simple example in this respect: a tank circuit of Fig. 21a is to be deattenuated by a partial coupled T.D.. In principal it is unavoidable, that the equivalent circuit of of this partial coupling (Fig. 21b) introduces a stray inductance "L_s", and thereby causes the characteristic curve pertaining to the terminals where the T.D. is to be inserted, contains an additional encirclement above the operating frequency range (3 mc) which cannot be influenced by a change of the tank circuit loading; the circuit is unstable (at approx. 150 mc).

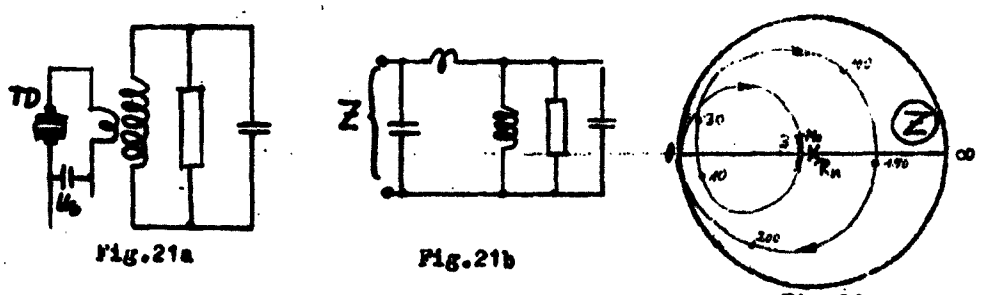


Fig.21a Fig.21b Fig.21c

Fig.21 : Stability problems at the deattenuation of a tank by a Td.

Now the task of the two-pole-stabilizer is to remove this additional encirclement without disturbing the characteristic curve within the operating frequency range. The simplest solution is obtained by using a RC-network (with the smallest possible inductance) which is connected directly parallel to the negativ resistance (Fig. 22a); the altered characteristic curve of Fig. 22b results and the circuit is now stable.

In other cases, in which the undesirable encirclement occurs at a considerably smaller frequency deviation from the operating freqnency range, an narrow band two-pole-stabilizer is used

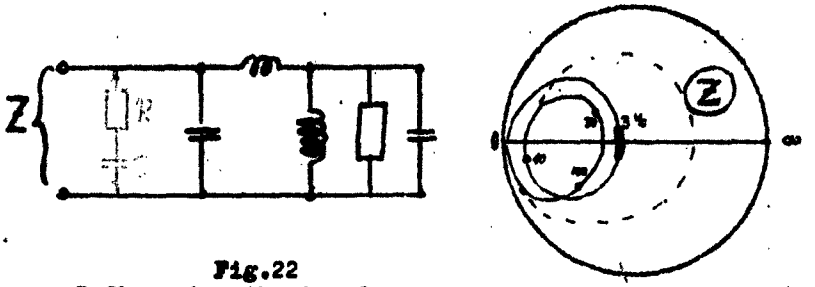


Fig.22
Influencing the impedance curve of an originally unstable circuit by a "two-pole-stabiliser".

Fig. 23b and c). The common feature of all these examples is the positive attenuating resistance. The practical design procedures are to be taken from the characteristic curve behaviour in the backward diagram.

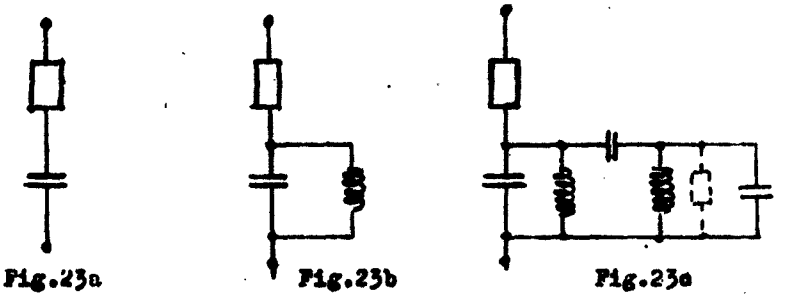


Fig.23a Fig.23b Fig.23c

For microwave applications the two-pole-stabiliser need not be inserted directly at the T.D., since the impedance behaviour along a transmission line is of a periodical occurance (for example resonator or antenna).

The primary advantage of this supplementary network is, that the stability check via characteristic curves need then only be carried for the operating frequency region where the impedance behaviour is usually known.

II. Impedance Measurements

A. Basic Design of the Tunnel Diode Circuit

The antenna which we have investigated was chosen to have a very simple form in order insure that the preliniary investigation is as simple as possible thus yielding reliable results. According to Fig. 24 the antenna is a unipole in which one vertical conductor is connected to the conducting ground plane and the other vertical conductor is connected to the coaxial input. The Tunnel Diode is located at the highest geometrical point of the radiator: between the two conductors. The bias voltage is fed to the tunnel diode via the two perpendicular conductors.

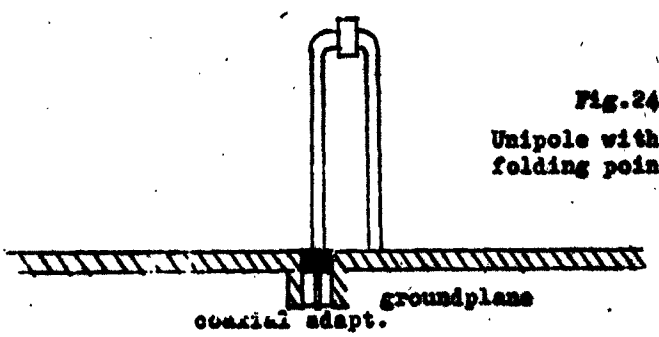


Fig.24
Unipole with TD in the folding point.

The most important requirement which is to be set on the system is that the tunnel diode is not in a state of self excitation. Due to the unavoidable reactive components of an antenna, the danger fo self excitation is especially great.if the dunnel diodes are combined with antennas. Two positive resistances can be connected in parallel to the T.D. (see Fig. 25) thus allowing for an adjustment of the resulting negative resistance. This arrangement is not only desirable for the measurement of the antenna feeding point impedance, but is also part of the stabilising arrangement which is tried here. The advantage of this arrangement for adjusting the negative resistance is that the operating point remains within the linear region of the

characteristic T.D. curve. In addition an adjustable parallel capacitance was used since many cases of self oscillation could be avoided by suitable adjustment of the capacitance.

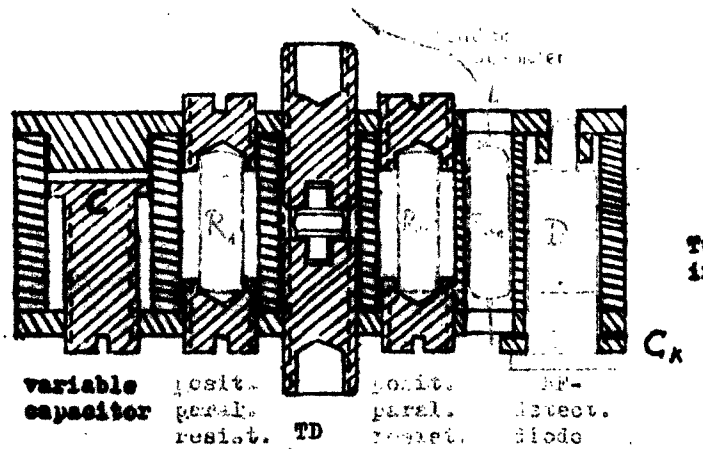


Fig.25
Tunnel diode mount in the folding point.

During the measurements the AC-voltage at the T.D. must be measured continuously for control. Therefore a diode (for detection of AC) is also connected in parallel to the T.D., which allows for measurement sensitivity of $3\cdot(10)^{-3}$ volts. The indication obtained from this diode arrangement allows for checking the circuit stability; in case of instability, the resistance and capacitance of the stabilising network can be varied until stability is obtained. The condi tion of self excitation can easily be observed in that corresponding voltage amplitude of 0.1 volts or more is measured at the test diode. Thus already a slight tendency towards a self excitation can easily be observed. In addition this arrangement enables the supervision of the AC voltage which exists at the T.D. due to the impedance measurement (AC voltage is fed to the antenna for this measurement).

This voltage should not be much larger than 0.02 volts between the two terminals of the T.D., since the tunnel diode impedance changes for the case of larger voltages due to the nonlinearity of the "T.D." current.

Since the "T.D." is to be operated at high frequencies and since the T.D. mount should not radiate, the latter should be rather

small in size and should be of extremely low inductance. Fig. 25 shows the construction of the mount whereas Fig. 26 shows the mount in the antenna.

Fig.26
View of the folding point.

The T.D. is placed in the center threaded hole of the mount and fastened via two screws, one located in each end of hole. Two similar threaded hole fastening arrangements are located adjacent to T.D. mount for the purpose of connected R_1 and R_2 in parallel to the T.D.. These two resistances determine the attenuating or loading resistance "R" of the stabilizing circuit. "C" is a variable capacitor. "D" is the detection diode which is used to measure the AC voltage.

One end of the diode is AC connected to the system via the capacitor "C_k". The resistance "R_m" serves as a feed- in for the DC current of the detection diode. "L" is the lead wire within the antenna conductor through which the DC current of the detection diode is accessible for measurement. The complete construction is schematically shown by Fig. 27.

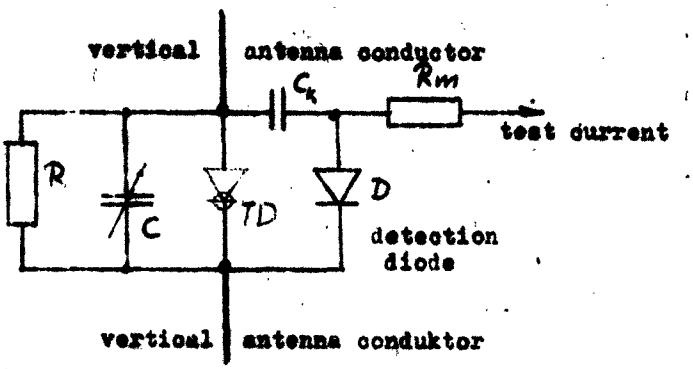


Fig.27
Circuit diagramm of the TD-mount in the folding point.

B. Measurement of Impedances containing negative resistances

The impedances were measured by using a slotted coaxial line. In accordance with Fig. 28 the line "L_s" is connected to the coaxial adapter. The slotted line is thus a part of the complete T.D. circuit and must be included in the stability consideration. Since for easy stabilisation the number of resonant frequencies of the circuit must be kept as small as possible, it is appropiate to terminate the input of the slotted line with a resistance "$R = Z_0$" (characteristic impedance of the line) which is frequency independent. Then the entire line behaves as a frequency independent resistance "Z_0" at the base of the antenna and does not contain any resonances. However the stabilization of the circuit via "R" and "C" connection at the T.D. location in accordance with Section IIA must be undertaken when the slotted line is connected to the circuit.

The test signal obtained from the test generator "M" is coupled out of the line via a loosely coupled capacitive probe "P_s" which projects slightly into the slot of the line. The loose coupling insures that the stabilized impedance behaviour is not disturbed. One leg of the unipole is grounded. The other leg serves (in addition to its radiation behaviour) as the lead for the DC bias of the T.D. in that it extends as the inner conductor of the slotted line and is accessible behind the 60 ohm

termination (the outer conducter of the slotted line is AC grounded via a large capacitor "C_a" which is connected in series to the outer conductor at the dissection of the same in the vicinity of the line termination). The test voltages obtained at the slotted line are very small due to the small voltage regulation of the T.D.. The voltage curve along the slotted line is measured. Since the capacitive probe is very loosely coupled to the line the measured voltages are very small and a sensitive receiver is required.

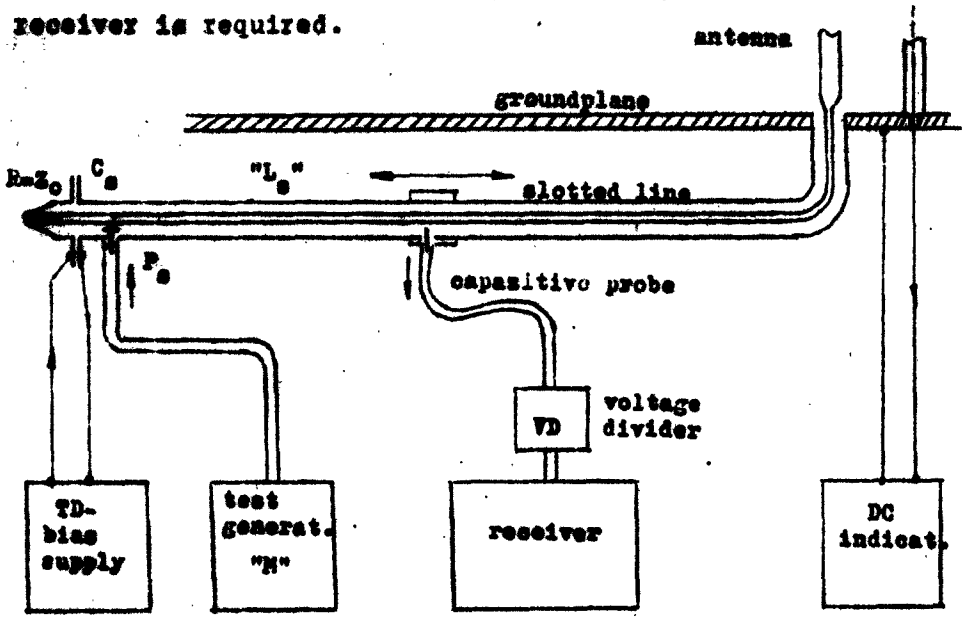


Fig.28 Test setup for impedance measurement.

Actually the measurement process consists in determining the maximum voltage "U_{max}" and the minimum voltage "U_{min}" along the line

$$VSWR = S = \frac{U_{max}}{U_{min}}$$

"S" as defined in this equation is determined by using a suitable calibrated voltage divider "VD". (In the measuring process the voltage at the receiver output is kept constant by adjusting

the VD; the attenuation of VD which has been adjusted to achieve this condition, is then recorded in each run.)

If the input impedance "Z = - R + jX" contains a negative real part "- R" then the circle diagram in the complex impedance plane must be extended in such a manner (as shown in Fig.29) that negative real parts can also be included. The diagram circles in the left side of the plane are the images of those in the right side of the plane. The VSWR values could lie on either the right hand (which contains positive resistive components), or the left hand side (which contains negative resitive components), since the measured VSWR does not give any indication as whether the real part of the impedance is negative or positive. The sign of the real part can be determined from the size of "U_{max}" of the circuit in Fig.28.

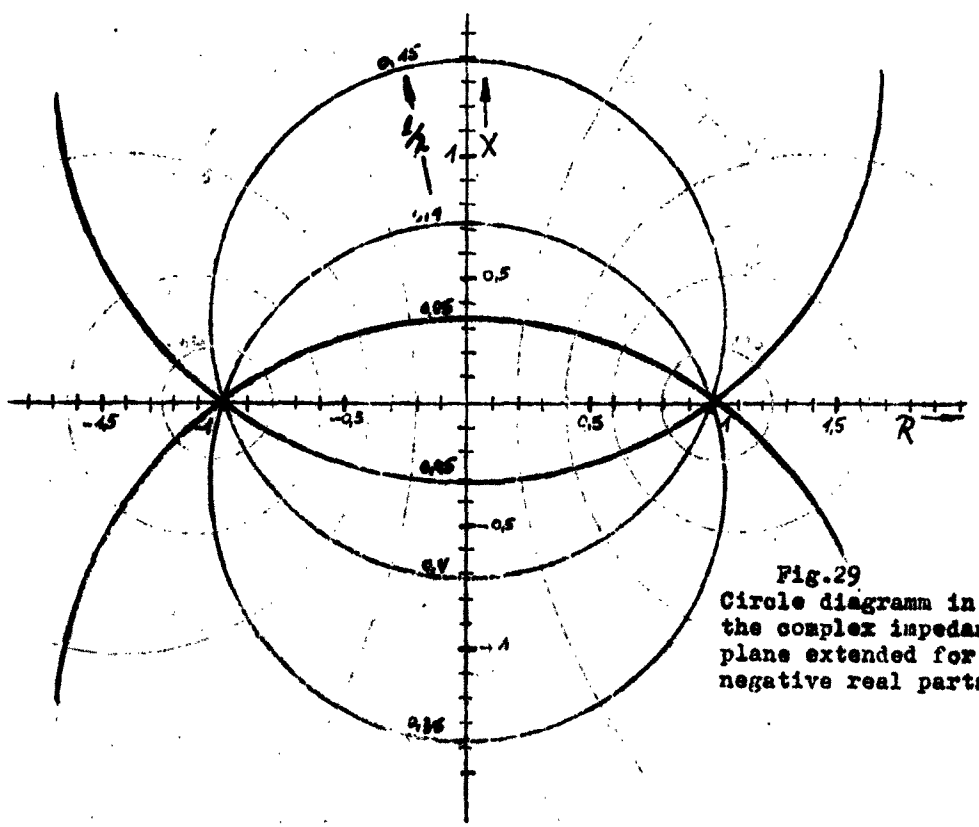


Fig.29
Circle diagramm in the complex impedance-plane extended for negative real parts.

Corresponding theory:

The generator in Fig. 28, which is loosely coupled to the line feeds the latter with a current "I" which is independent of the load (Fig. 30a). The termination "$R = Z_0$" at the left hand side of the line can be transformed to the location of the coupling point (see Fig. 30b) "I" and "Z_0" together form a current source. The location of a voltage maximum along the line is to be sought. Then the current source and the load "Z" which is to be measured is transformed to the location of a voltage maximum as shown in Fig. 30c (which does not change in the transformation).

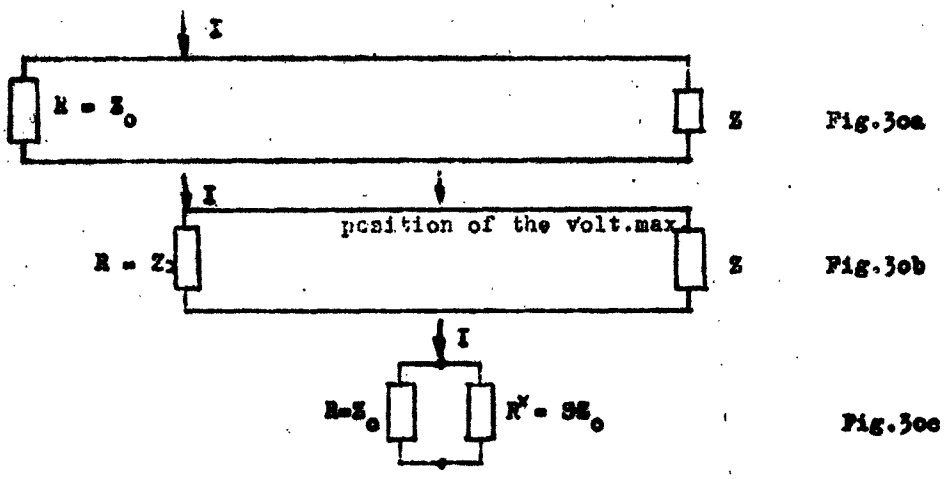


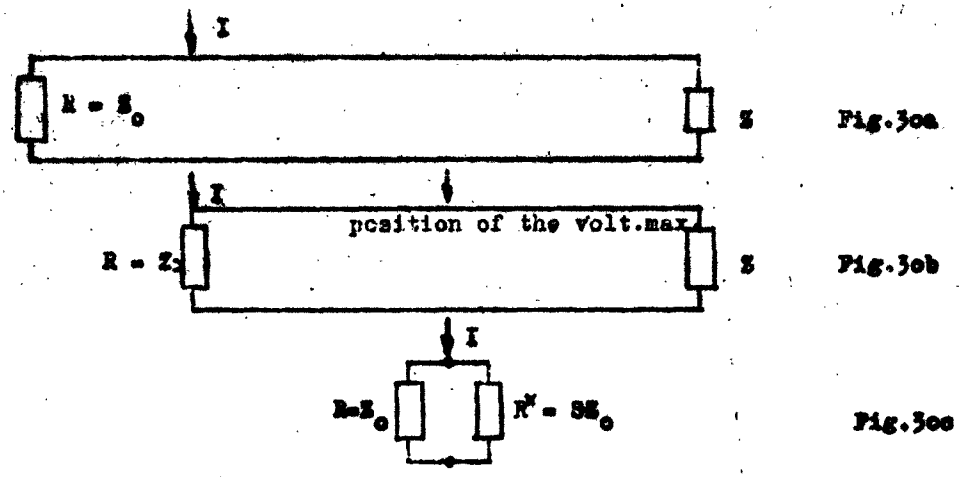
Fig.30 : Transmission line having a termination which includes a positive or a negative realpart.

As a result of this transformation, "Z" transforms to a real resistance $R = S\,Z_L$ when the real part of "Z" is positive, and transforms into a negative real resistance $R^x = -S \cdot Z_L$ when the real part of "Z" is negative. The current "I" divides itself thus between the resistance "R" and the resistance "R^x". In this manner the maximum voltage, as described by the following equation, is obtained for Fig. 30c.

$$U_{max} = |I| \cdot Z_L \left(\frac{S}{S\pm 1}\right) \qquad (11)$$

Corresponding theory:

The generator in Fig. 28, which is loosely coupled to the line feeds the latter with a current "I" which is independent of the load (Fig. 30a). The termination "R = Z_o" at the left hand side of the line can be transformed to the location of the coupling point (see Fig. 30b) "I" and "Z_o" together form a current source. The location of a voltage maximum along the line is to be sought. Then the current source and the load "Z" which is to be measured is transformed to the location of a voltage maximum as shown in Fig. 30c (which does not change in the transformation).



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$$U_{max} = |I| \cdot Z_L \left(\frac{S}{S-1}\right) \qquad (11)$$

The sign in the denominator is the same as the sign of the real part of "Z".

At first the antenna is replaced by a matched resistance "$R = Z_o$" Then the following voltage is measured along the line since $S = 1$:

$$|U_o| = \frac{1}{2} |I| Z_o \qquad (12)$$

If the antenna is now inserted as a complex load "Z", then the following is valid if the real part of "Z" is positive:

$$U_o = U_{max} \geq 2 U_o \qquad (13)$$

If "Z" is a pure resetance then "$U_{max} = 2 U_o$". If "Z" contains a negative real part, then the following is valid:

$$U_{max} > 2 U_o \qquad (14)$$

and "U_{max}" can have an arbitrary large value. By measuring U_{max} and comparing it with U_o the sign of R^x can be found by help of (13) or (14).

C. Example of a Measurement on a Folded Dipole with T.D.

The following example has been chosen in order to explain the principles of the measurement technique and thus the example is rather simple. No particularly interesting application of a T.D. is therein described. An unsymmetrical antenna having coaxial feed-in allows for simpler measurement as compared to a symmetrical antenna Therefore one half of a folded dipole (that portion above the conducting plane) was used.

The T.D. is located in the crest of the antenna and its associated impedance also influences the measured impedance at the feeding point. If the bias voltage of the T.D. is changed, different positive and negative values of the T.D. resistance can be obtained. Fig. 32 shows the measured antenna input impedance for various diode resistance values.

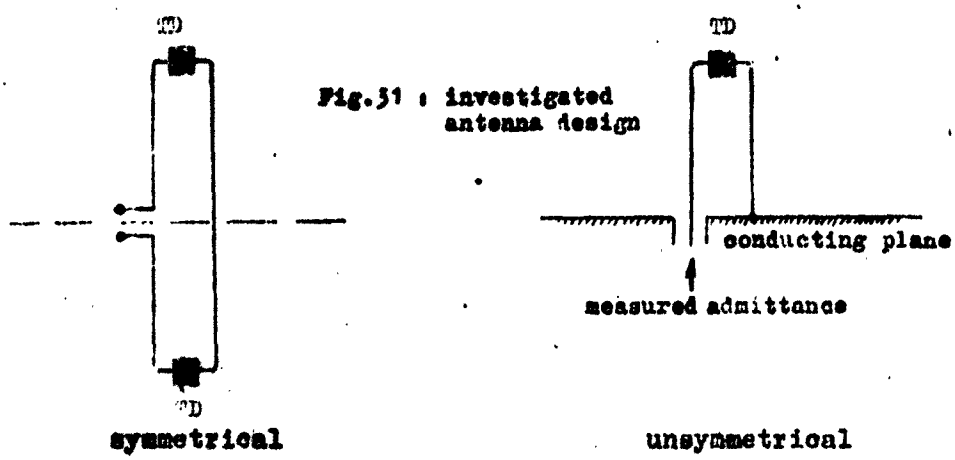

Fig.31 : investigated antenna design

Therefore cases exist in which the input admittance of the antenna contains a negative real part; in this case the antenna may operate as an amplifier. Since the curve of the input admittance contains loops in the admittance plane, a certain wide band behaviour can be obtained if the antenna is matched.

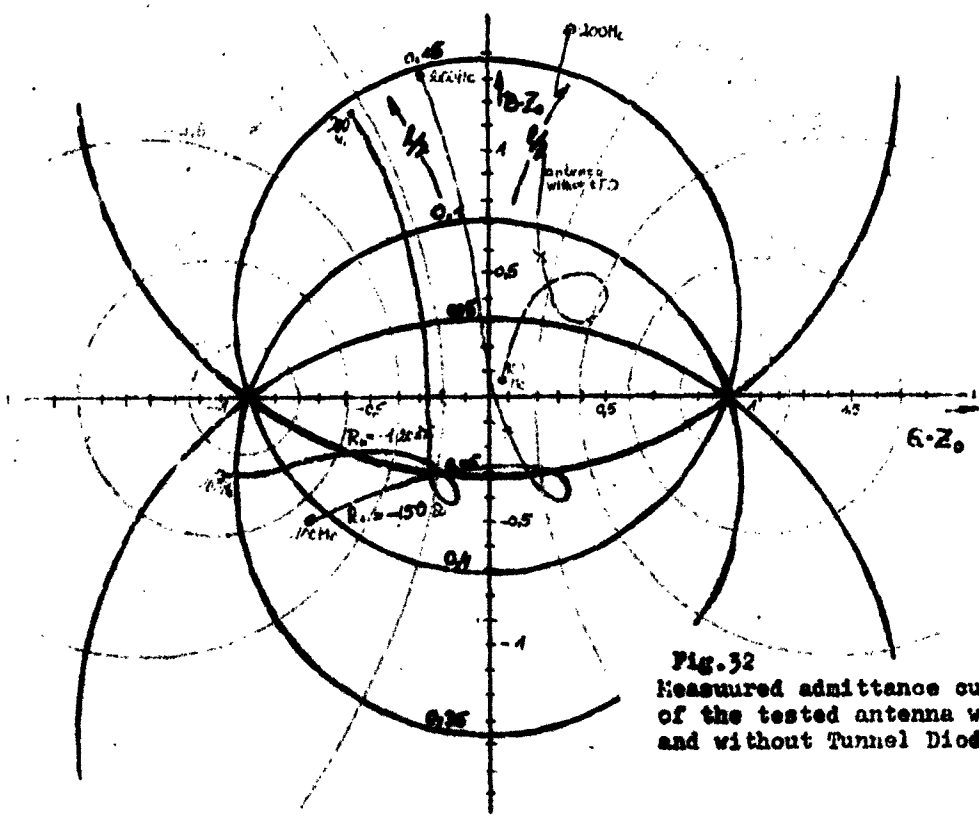

Fig.32
Measured admittance curves of the tested antenna with and without Tunnel Diode.

Bibliography

[1] F. Strecker " Die elektrische Selbsterregung." Hirzel Verlag Stuttgart 1947

[2] E. Görk " Stabilitätskriterien." A.E.Ü. 4 (1950) page 89-96

[3] D. Böhne " Impedanzmessungen an Tunneldioden im Mikrowellengebiet." Internal report of the Institut für Hochfrequenztechnik der Techn. Hochsch. München

[4] J. Steinkamp " Impedanz einer Antenne mit Tunneldiode." Diplomarbeit at the Institut für Hochfrequenztechnik der Technischen Hochschule München.

Glossary of Symbols

p_o	Eigen value of a network.
p	Complex frequency
σ	Real part of the complex frequency
ϕ	Rotating angle of a vector, drawn from the origin to a curve.
Y_b	Admittance at an branch of a network. (Especially of that one, which contains the negative resistor.)
Y	Admittance at those terminals, at which the real negative resistor is to be inserted.
Y_e	Admittance at those terminals, at which the tunnel diode is to be inserted.
S	Voltage standing wave ratio.
Z_o	Charakteristic impedance of a line.

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